Chapter 8
Planning GPS Control Surveys

8-1. General

Using differential carrier phase GPS surveying to establish control for USACE civil and military projects requires operational and procedural specifications that are a project-specific function of the control being established. To accomplish these surveys in the most efficient and cost-effective manner, and to ensure that the required accuracy criteria are obtained, a detailed survey planning phase is essential. This chapter defines GPS survey design criteria and related observing specifications required to establish control for USACE military construction and civil works projects. Information on cost for GPS surveys can be found in Chapter 12, and information on using GPS for hydrographic surveys can be found in EM 1110-2-1003.

8-2. Required Project Control Accuracy

The first step in planning GPS control surveys is to determine the ultimate accuracy requirements. Survey accuracy requirements are a direct function of specific project functional needs, that is, the basic requirements needed to support planning, engineering design, maintenance, operations, construction, or real estate. This is true regardless of whether GPS or conventional surveying methods are employed to establish project control. Most USACE military and civil works engineering/construction activities require relative accuracies (i.e., accuracies between adjacent control points) ranging from 1:1,000 to 1:50,000, depending on the nature and scope of the project. Few USACE projects demand relative positional accuracies higher than the 1:50,000 level (Second-Order, Class I). Since the advent of GPS survey technology, there has been a tendency to specify higher accuracies than necessary. Specifying higher accuracy levels than those minimally required for the project can unnecessarily increase project costs.

a. Project functional requirements. Project functional requirements must include planned and future design, construction, and mapping activities. Specific control density and accuracy are designed from these functional requirements.

(1) Density of control within a given project is determined from factors such as planned construction, site plan mapping scales, master plan mapping scale, and dredging and hydrographic survey positioning requirements.

(2) The relative accuracy for project control is also determined based on mapping scales, design/construction needs, type of project, etc. Most site plan mapping for design purposes is performed and evaluated relative to American Society of Photogrammetry and Remote Sensing (ASPRS) standards. These standards apply to photogrammetric mapping, plane table mapping, total station mapping, etc. Network control must be of sufficient relative accuracy to enable hired-labor or contracted survey forces to reliably connect their supplemental mapping work.

b. Minimum accuracy requirements. Project control surveys shall be planned, designed, and executed to achieve the minimum accuracy demanded by the project's functional requirements. In order to most efficiently utilize USACE resources, control surveys shall not be designed or performed to achieve accuracy levels that exceed the project requirements. For instance, if a Third-Order, Class I accuracy standard (1:10,000) is required for offshore dredge/survey control on a navigation project, field survey criteria shall be designed to meet this minimum standard.

c. Achievable GPS accuracy. As stated previously, GPS survey methods are capable of providing significantly higher relative positional accuracies with only minimal field observations, as compared with conventional triangulation, trilateration, or EDM traverse. Although a GPS survey may be designed and performed to support lower accuracy project control requirements, the actual results could generally be several magnitudes better than the requirement. Although higher accuracy levels are relatively easily achievable with GPS, it is important to consider the ultimate use of the control on the project in planning and designing GPS control networks. Thus, GPS survey adequacy evaluations should be based on the project accuracy standards, not those theoretically obtainable with GPS.

(1) For instance, an adjustment of a pair of GPS-established points may indicate a relative distance accuracy of 1:800,000 between them. These two points may be subsequently used to set a dredging baseline using 1:2,500 construction survey methods; and from 100-ft-spaced stations on this baseline, cross sections are projected using 1:500 to 1:1,000 relative accuracy methods (typical hydrographic surveys). Had the GPS-observed baseline been accurate only to 1:20,000, such a closure would still have easily met the project's functional requirements.

(2) Likewise, in plane table topographic (site plan) mapping or photogrammetric mapping work, the difference between 1:20,000 and 1:800,000 relative accuracies is not perceptible at typical USACE mapping/construction scales (1:240 to 1:6,000), or ensuring supplemental compliance with ASPRS standards. In all cases of planimetric and topographic mapping work, the primary control network shall be of sufficient accuracy such that ASPRS standards can be met when site plan mapping data are derived from such points. For most large-scale military and civil mapping work performed by USACE, Third-Order relative accuracies are adequate to control planimetric and topographic features within the extent of a given sheet/map or construction site. On some projects covering large geographical areas (e.g., reservoirs, levee systems, installations), this Third-Order mapping control may need to be connected to/with a Second-Order (Class I or II) network to minimize scale distortions over longer reaches of the project.

(3) In densifying control for GIS databases, the functional accuracy of the GIS database must be kept in perspective with the survey control requirements. Performing 1:100,000 accuracy surveys for a GIS level containing 1-acre cell definitions would not be cost-effective; sufficient accuracy could be obtained by scaling relative coordinates from a U.S. Geological Survey (USGS) quadrangle map.

8-3. General GPS Network Design Factors

Some, but not all, of the factors to be considered in designing a GPS network (and subsequent observing procedure) should include the following:

a. Project size. The extent of the project will affect the GPS survey network shape. Many civil works navigation and flood control projects are relatively narrow in lateral extent but may extend for many miles longitudinally. Alternatively, military installations or reservoir/recreation projects may project equally in length and breadth. The optimum GPS survey design will vary considerably for these different conditions.

b. Required density of control. The type of GPS survey scheme used will depend on the number and spacing of points to be established, which is a project-specific requirement. In addition, maximum baseline lengths between stations and/or existing control are also prescribed. Often, a combination of GPS and conventional survey densification will prove to be the most cost-effective approach.

c. Absolute GPS reference datums. Coordinate data for GPS baseline observations are referenced and reduced relative to WGS 84, an earth-centered (geocentric) coordinate system. This system is not directly referenced to but is closely related to, for all practical purposes, GRS 80 upon which North American Datum of 1983 (NAD 83) is related (for CONUS work). GPS data reduction and adjustment are normally performed using the WGS 84 earth-centered (geocentric) coordinate system (X-Y-Z), with baseline vector components (ΔX, ΔY, ΔZ) measured relative to this coordinate system. Although baseline vectors are measured relative to the WGS 84 system, for most USACE engineering and construction applications these data may be used in adjustments on NAD 27 (Clarke 1866). (See paragraphs 3-4 and 4-1.)

(1) If the external network being connected (and adjusted to) is the published NAD 83, the GPS baseline coordinates may be directly referenced on the GRS 80 ellipsoid since they are nearly equal. All supplemental control established is therefore referenced to the GRS 80/NAD 83 coordinate system.

(2) If a GPS survey is connected to NAD 27 (SPCS 27) stations which were not adjusted to the NAD 83 datum, then these fixed points may be transformed to NAD 83 coordinates using USACE program CORPSCON (see EM 1110-1-1004) and the baseline reductions and adjustment performed relative to the GRS 80 ellipsoid. This method is recommended for USACE projects, only if resurveying is not a viable option.

(3) Alternatively, GPS baseline connections to NAD 27 (SPCS 27) project control may be reduced and adjusted directly on that datum with resultant coordinates on the NAD 27. Geocentric coordinates on the NAD 27 datum may be computed using the transformation algorithms given in Chapter 11. Refer also to EM 1110-1-1004 regarding state plane coordinate transforms between SPCS 27 and SPCS 83 grids. Conversions of final adjusted points on the NAD 27 datum to NAD 83 may also be performed using CORPSCON.

(4) Ellipsoid heights h referenced to the GRS 80 ellipsoid differ significantly from the orthometric elevations H on NGVD 29, NAVD 88, or dynamic/hydraulic elevations on the IGLD 55, IGLD 85. This difference (geoid separation, or N) can usually be ignored for horizontal control. This implies N is assumed to be zero and $h = H$ where the elevation may be measured, estimated, or scaled at the fixed point(s). See Chapter 6 for using GPS for vertical surveys.

(5) Datum systems other than NAD 27/NAD 83 will be used in OCONUS locations. Selected military operational requirements in CONUS may also require non-NAD datum references. It is recommended that GPS baselines be directly adjusted on the specific project datum.

d. Connections to existing control. For most static and kinematic GPS horizontal control work, at least two existing control points should be connected for referencing and adjusting a new GPS survey (Table 8-1). Existing points may be part of the NGRS or in-place project control which has been adequately used for years. Additional points may be connected if practical. In some instances, a single existing point may be used to generate spurred baseline vectors for supplemental construction control.

(1) Connections with existing project control. The first choice for referencing new GPS surveys is the existing project control. This is true for most surveying, not just GPS, and has considerable legal basis. Unless a newly authorized project is involved, long-established project control reference points should be used. If the project is currently on a local datum, then a supplemental tie to the NGRS should be considered as part of the project.

(2) Connections with NGRS. Connections with the NGRS (i.e., National Ocean Service/National Geodetic Survey control on NAD 83) are preferred where prudent and practical. As with conventional USACE surveying, such connections to the NGRS are not mandatory. In many instances, connections with the NGRS are difficult and may add undue cost to a project with limited resources. When existing project control is known to be of poor accuracy, then ties (and total readjustment) to the NGRS may be warranted. Sufficient project funds should have been programmed to cover the additional costs of these connections, including data submittal and review efforts if such work is intended to be included in the NGRS. (See paragraph 1-8*c* regarding advance programming requirements.)

(3) Mixed NGRS and project control connections. On existing projects, NGRS-referenced points should not be mixed with existing project control. This is especially important if existing project control was poorly connected with the older (NAD 27) NGRS, or if the method of this original connection is uncertain. Since NGRS control has been readjusted to NAD 83 (including subsequent high-precision HARNS readjustments of NAD 83) and most USACE project control has not, problems may result if these schemes are mixed indiscriminately. If a decision is made to establish and/or update control on an existing project, and connections with the NGRS (NAD 83/86) are required, then all existing project control points must be resurveyed and readjusted. Mixing different reference systems can result in different datums, with obvious adverse impacts on subsequent construction or boundary reference. It is far preferable to use "weak" existing (long-established) project control (on NAD 27 or whatever datum) for reference than to end up with a mixture of different systems or datums. See EM 1110-1-1004 for further discussion.

(4) Accuracy of connected reference control. Ideally, connections should be made to control of a higher order of accuracy than that intended for the project. In cases where NGRS control is readily available, this is usually the case. However, when only existing project control is available, connection and adjustment will have to be performed using that reference system, regardless of its accuracy. GPS baseline measurements should be performed over existing control to assess its accuracy and adequacy for adjustment, or to configure partially constrained adjustments.

(5) Connection constraints. Although Table 8-1 requires only a minimum of two existing stations to reliably connect GPS static and kinematic surveys, it may often be prudent to include additional NGRS and/or project points, especially if the existing network is of poor reliability. Adding additional points provides redundant checks on the surrounding network. This allows for the elimination of these points should the final constrained adjustment indicate a problem with one or more of the fixed points.

(a) Table 8-1 indicates the maximum allowable distance from the existing network that GPS baselines should extend.

(b) Federal Geodetic Control Subcommittee (FGCS) GPS standards (FGCC 1988) require connections to be spread over different quadrants relative to the survey project. Other GPS standards suggest an equilateral distribution of fixed control about the proposed survey area. These requirements are unnecessary for USACE work. The value shown in Table 8-1 (for Second-Order, Class I) is only suggested and not mandatory.

e. Location feasibility and field reconnaissance. A good advance reconnaissance of all marks within the project is crucial to the expedient and successful

Table 8-1
GPS Survey Design, Geometry, Connection, and Observing Criteria

	Classification Order			
Criterion	2nd, **I**	2nd, **II**	3rd, **I**	3rd, **II**
Relative accuracy				
ppm	20	50	100	200
1 part in	50k	20k	10k	5k
Required connections to existing horizontal control				
NGRS network	W/F/P			
Local project network	Yes			
Baseline observation check required over existing control	Yes	W/F/P	W/F/P	No
Number of connections with existing network (NGRS or local project control)				
Minimum	2	2	2	2
Optimum	3	3	2	2
New point spacing, m, not less than	1,000	500	200	100
Maximum distance from network to nearest control point in project, km	50	50	50	50
Minimum network control quadrant location (relative to project center)	2	N/R	N/R	N/R
Multiple station occupations (static GPS surveys)				
% Occupied three times	N/R	N/R	N/R	N/R
% Occupied two times	N/R	N/R	N/R	N/R
Repeat baseline observations (% of total baselines)	0	0	0	0
Master or fiducial stations required	W/F/P	No	No	No
Loop closure requirements:				
Maximum number of baselines/loop	10	20	20	20
Maximum loop length, km, not to exceed	100	200	N/R	N/R
Loop misclosure, ppm, not less than	20	50	100	200
Single spur baseline observations				
Allowed per order/class	No	No	Yes	Yes
Number of sessions/baseline	-	-	2	2
Required tie to NGRS	-	-	No	No
Field observing criteria -- static GPS surveys				
Required antenna phase height measurement per session	2	2	2	2
Meteorological observations required	No	No	No	No
Two frequency L1/L2 observations required:				
< 50-km lines	No	No	No	No
> 50-km lines	Yes	Yes	Yes	Yes

(Continued)

Table 8-1
(Concluded)

Criterion	Classification Order 2nd, **I**	2nd, **II**	3rd, **I**	3rd, **II**
Recommended minimum observing time (per session), min	60	45	30	30
Minimum number of sessions per GPS baseline	1	1	1	1
Satellite quadrants observed (minimum number)	3 W/F/P	N/R	N/R	N/R
Minimum obstruction angle above horizon, deg	15	15	15	15
Maximum HDOP/VDOP during session	N/R	N/R	N/R	N/R
Photograph and/or pencil rubbing required	A/R	No	No	No
Kinematic GPS surveying				
Allowable per survey class	Yes	Yes	Yes	Yes
Required tie to NGRS	W/F/P	W/F/P	No	No
Measurement time/baseline, min	(follow manufacturer's specifications) A/R			
Minimum number of reference points:	2	2	1-2	1
Preferred references	2	2	2	1
Maximum PDOP		15		
Minimum number of observations from each reference station	2	2	2	2
Adjustment and data submittal requirements				
Approximate adjustments allowed	Yes	Yes	Yes	Yes
Contract acceptance criteria				
Type of adjustment	Free (unconstrained)			
Evaluation statistic	Relative distance accuracies			
Error ellipse sizes	(not used as criteria)			
Histograms	(not used as criteria)			
Reject criteria				
Statistic	Normalized residual			
Standard	±3 * SEUW			
Optimum/nominal weighting				
Horizontal	± 5 + 2 ppm			
Vertical	± 10 + 2 ppm			
Optimum variance of unit weight	between 0.5 and 1.5			
GPS station/session data recording format	Bound field survey book or form			
Final station descriptions	Standard DA form			
FGCS/NGS Bluebook required	No			
Written project/adjustment report required	Yes			

Notes:

1. Abbreviations used in this table are explained as follows:
   W/F/P--Where feasible and practical.
   N/R--No requirement for this specification--usually indicates variance with provisional FGCC GPS specifications.
   A/R--As required in specific project instructions or manufacturer's operating manual.
   SEUW--Standard error of unit weight.
2. Classification orders refer to intended survey precision for USACE application, not necessarily FGCC standards designed to support national network densification.

completion of a GPS survey. The site reconnaissance should ideally be completed before the survey is started. The surveyor should also prepare a site sketch and brief description on how to reach the point since the individual performing the site reconnaissance may not be the surveyor that returns to occupy the known or unknown station.

(1) Project sketch. A project sketch should be developed before any site reconnaissance is performed. The sketch should be on a 7-1/2-min USGS quadrangle map or other suitable drawing. Drawing the sketch on the map will assist the planner in determination of site selections and travel distances between stations.

(2) Station descriptions and recovery notes. Station descriptions for all new monuments will be developed as the monumentation is performed. The format of these descriptions will follow that stated in EM 1110-1-1002. Recovery notes should be written for existing NGRS network stations and project control points, as detailed in EM 1110-1-1002. Estimated travel times to all stations should be included in the description. Include road travel time, walking time, and GPS receiver breakdown and setup time. These times can be estimated while performing the initial reconnaissance. A site sketch shall also be made on the description/recovery form. Examples of site reconnaissance reports are shown in Figures 8-1 and 8-2. A blank reconnaissance report form is included as Worksheet 8-1 (Figure 8-3), which may be used in lieu of a standard field survey book.

(3) Way point navigation. Way point navigation is an option on some receivers, allowing the user to enter geodetic position (usually latitude and longitude) of points of interest along a particular route the user may wish to follow. The GPS antenna, fastened to a vehicle or range pole, and receiver can then provide the user with navigational information. The navigational information may include the distance and bearing to the point of destination (stored in the receiver), the estimated time to destination, and the speed and course of the user. The resultant message produced can then be used to guide the user to the point of interest. Way point navigation is an option that, besides providing navigation information, may be helpful in the recovery of control stations which do not have descriptions. If the user has the capability of real-time code phase positioning, the way point navigational accuracy can be in the range of 0.5 - 10 m.

(4) Site obstruction/visibility sketches. The individual performing the site reconnaissance should record the azimuth and vertical angle of all obstructions. The azimuths and vertical angles should be determined with a compass and inclinometer. Because obstructions such as trees and buildings cause the GPS signal transmitted from the GPS satellite to be blocked, the type of obstruction is also an important item to be recorded, see Figure 8-2. The type of obstruction is also important to determine if multipath might cause a problem. Multipath is caused by the reflection of the GPS signal by a nearby object producing a false signal at the GPS antenna. Buildings with reflective surfaces, chain-link fences, and antenna arrays are objects that may cause multipath. The site obstruction data are needed to determine if the survey site is suitable for GPS surveying. Obstruction data should be plotted on a Station Visibility Diagram, as shown in Figure 8-4. (A blank copy of this form is provided as Worksheet 8-2 (Figure 8-5).) GPS surveying does require that all stations have an unobstructed view 15 deg above the horizon, and satellites below 10 deg should not be observed.

(5) Suitability for kinematic observations. Clear, obstruction-free projects may be suitable for kinematic GPS surveys as opposed to static. The use of kinematic observations will increase productivity by a factor of 5 to 10 over static methods, while still providing adequate accuracy levels. On many projects, a mixture between both static and kinematic GPS observations may prove to be most cost-effective.

(6) Monumentation. All monumentation should follow the guidelines of EM 1110-1-1002.

(7) On-site physical restrictions. The degree of difficulty in occupying points due to such factors as travel times, site access, multipath effects, and satellite visibility should be anticipated. The need for redundant observations, should reobservations be required, must also be considered.

(8) Checks for disturbed existing control. Additional GPS baselines may need to be observed between existing NGRS/project control to verify their accuracy and/or stability.

(9) Satellite visibility limitations. For most of the Continental United States, there are at least four to five satellites in view at all times. However, some areas may have less during times of satellite maintenance or unhealthy satellites. Satellite visibility charts of the GPS satellite constellation play a major part in optimizing network configurations and observation schedules.

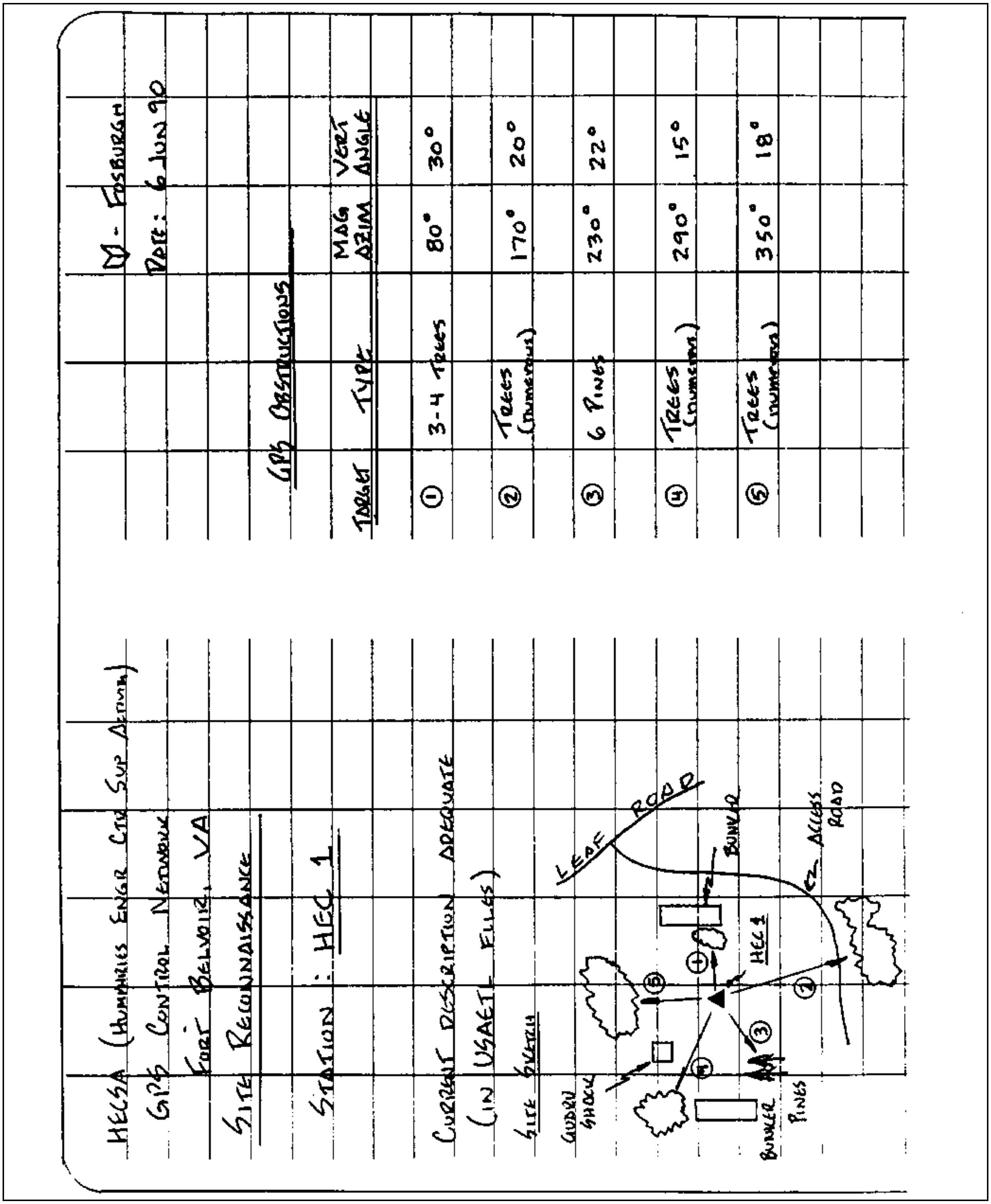

Figure 8-1. Sample site reconnaissance sketch

SITE RECONNAISSANCE/REPORT ON CONDITION OF SURVEY MARK

Project for Which Reconnaissance was Performed DWORSHAK DAM

Station Name OROFINO Year Established 1933

State Code ID County POTTER Map Scale 1:24,000

Organization's Mark C & GS Map Sheet CLEARWATER

Search Performed By K. SMITH Date 4/12/89

Organization WALLA WALLA DISTRICT

Exact Stamping OROFINO 1933 Condition GOOD

Please report on the thoroughness of the search in case the mark was not recovered. Suggest changes in description, need for repairing or moving the mark, or other pertinent facts. Record letters and numbers found stamped in (not cast in) the mark.

THE MARK WAS RECOVERED USING THE 1970 DESCRIPTION. ADDITIONAL DESCRIPTIVED DATA: THE MARK IS 89.7' W OF PP#6342, 62.4' NE OF AN 18" MAPLE, 42.0' S OF A 10" SPRUCE AND 2' E OF AN ORANGE WITNESS POST.
RECOVERED REFERENCE MARK OROFINO NO. 1 1933 GOOD
" " " OROFINO NO. 3 1970 GOOD

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TRAVEL TIME BY 2-WHEEL DRIVE VEHICLE FROM CLEARWATER IS APPROX. 15 MINUTES.

SKETCH

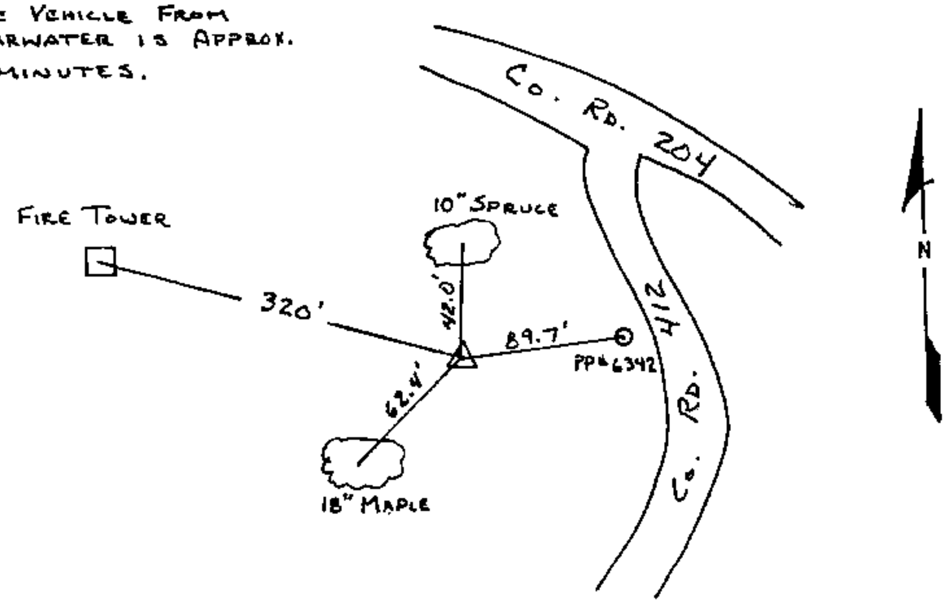

Figure 8-2. Reconnaissance report on condition of survey

SITE RECONNAISSANCE/REPORT ON CONDITION OF SURVEY MARK

Project for Which Reconnaissance was Performed ______________________

Station Name ____________________________ Year Established ______

State Code ____ County __________________ Map Scale ____________

Organization's Mark _____________________ Map Sheet ____________

Search Performed By ________________________ Date ______________

Organization ____

Exact Stamping ______________________ Condition ______________

Please report on the thoroughness of the search in case the mark was not recovered. Suggest changes in description, need for repairing or moving the mark, or other pertinent facts. Record letters and numbers found stamped in (not cast in) the mark.

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SKETCH

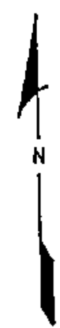
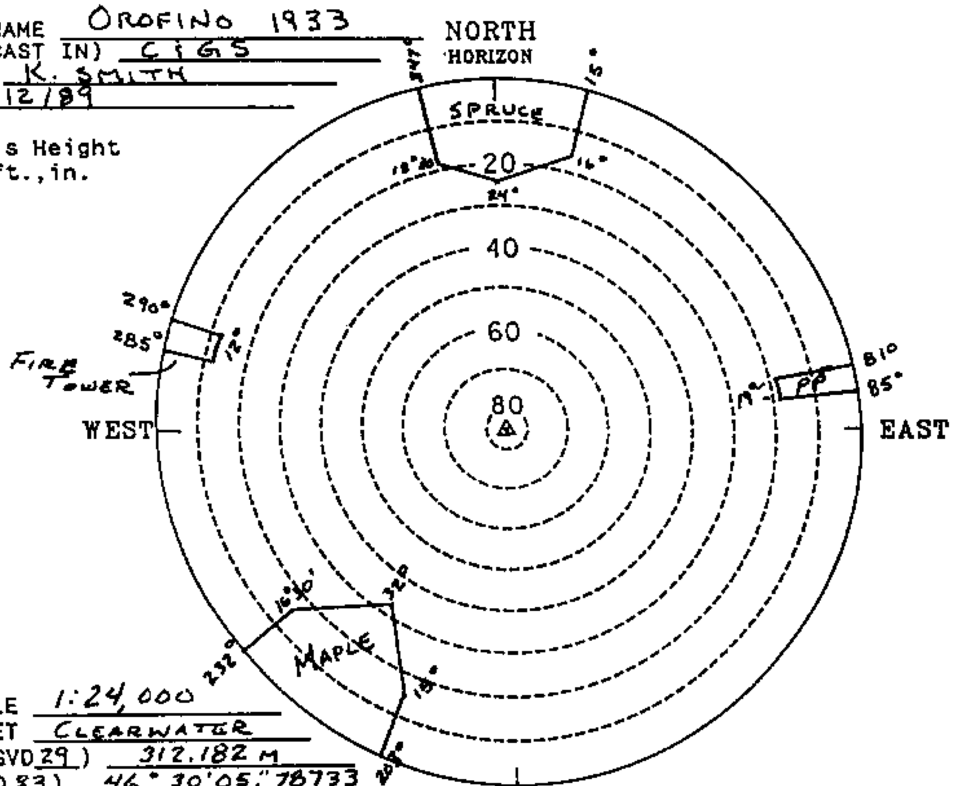


Figure 8-3. Worksheet 8-1, Site Reconnaissance Report form

STATION VISIBILITY DIAGRAM

STATION NAME OROFINO 1933
AGENCY (CAST IN) C & GS
OBSERVER K. SMITH
DATE 4/12/89

Observer's Height
5' 10" ft.,in.



MAP SCALE 1:24,000
MAP SHEET CLEARWATER
ELEV (NGVD 29) 312.182 M
LAT (NAD 83) 46° 30' 05.78733" N
LONG (NAD 83) 116° 19' 27.36405" W

Indicate the horizontal and vertical limits of all objects obstucting veiw of the sky exceeding 15 degrees above the horizon.

NO.	AZIMUTH	VERT ANGLE	DESCRIPTION	NO.	AZIMUTH	VERT ANGLE	DESCRIPTION
1	347°00'	18° 30'	EDGE SPRUCE	11			
2	358°30'	24°00'	PEAK SPRUCE	12			
3	15°00'	16°00'	EDGE SPRUCE	13			
4	81°00'	19°00'	N/EDGE PP	14			
5	85°30'	19°00'	S/EDGE PP	15			
6	203°00'	15°00'	EDGE MAPLE	16			
7	215°30'	32°00'	PEAK MAPLE	17			
8	232°00'	16°30'	EDGE MAPLE	18			
9				19			
10				20			

Indicate distance, direction, frequency and power of known RF sources.
Indicate distance, horizontal and vertical limits of any object in the vicinity that <u>may</u> cause radio signals to be reflected (multipath).

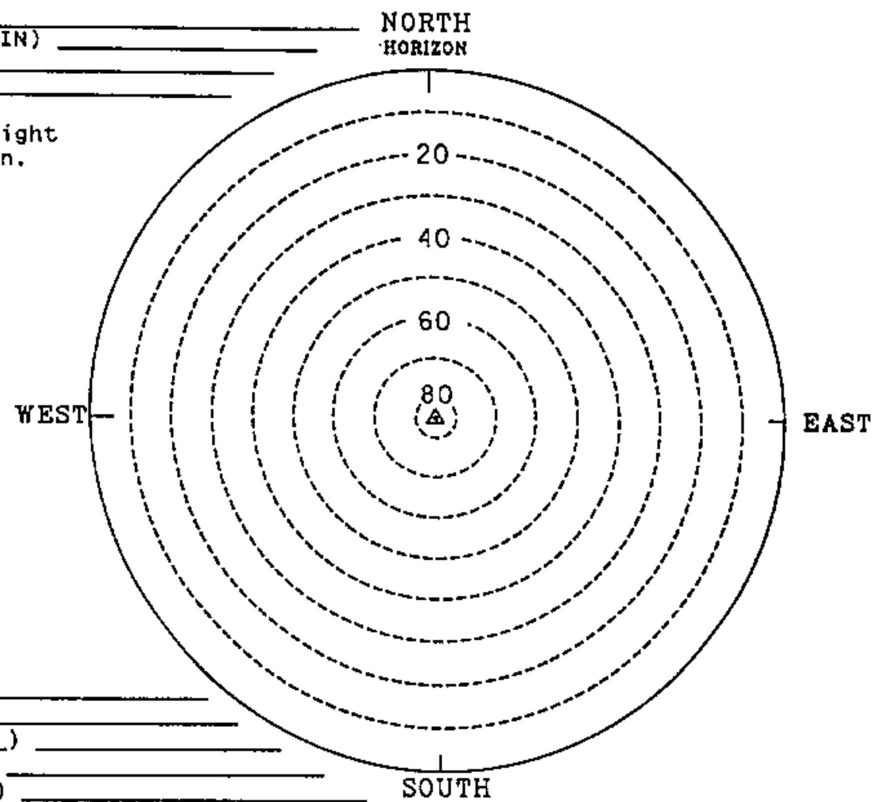
1. 320' 285° TO 290° VERT ∡ 12° FIRE TOWER
2. (DUE TO DISTANCE FROM STATION & LOW ELEVATION ANGLE, THIS IS
3. PROBABLY NOT A THREAT OF CAUSING MULTIPATH)

Figure 8-4. Sample station visibility diagram

STATION VISIBILITY DIAGRAM

STATION NAME ____________________
AGENCY (CAST IN) ____________________
OBSERVER ____________________
DATE ____________________

Observer's Height
________ ft.,in.



MAP SCALE ____________________
MAP SHEET ____________________
ELEV (NGVD___) ____________________
LAT (NAD___) ____________________
LONG (NAD___) ____________________

Indicate the horizontal and vertical limits of all objects obstucting veiw of the sky exceeding 15 degrees above the horizon.

NO.	AZIMUTH	VERT ANGLE	DESCRIPTION	NO.	AZIMUTH	VERT ANGLE	DESCRIPTION
1				11			
2				12			
3				13			
4				14			
5				15			
6				16			
7				17			
8				18			
9				19			
10				20			

Indicate distance, direction, frequency, and power of known RF sources. Indicate distance, horizontal and vertical limits of any object in the vicinity that *may* cause radio signals to be reflected (multipath).

1. ____________________
2. ____________________
3. ____________________

Figure 8-5. Worksheet 8-2, Station Visibility Diagram

(10) Station intervisibility requirements. Project specifications may dictate station intervisibility for azimuth reference. This may constrain minimum station spacing.

f. Multiple/repeat baseline connections. Table 8-1 lists recommended criteria for baseline connections between stations, repeat baseline observations, and multiple station occupations. Many of these standards were developed by FGCS for performing high-precision geodetic control surveys such that extensive redundancy will result from the collected data. Since the purpose of these geodetic densification surveys is markedly different from USACE control densification, the need for such high observational redundancy is also different. Adding redundant baseline/station occupations may prove prudent on some remote projects where accessibility is difficult.

g. Loop requirements. Loops (i.e., traverses) provide the mechanism for performing field data validation as well as final adjustment accuracy analysis. Since loops of GPS baselines are comparable to traditional EDM/taped traverse routes, misclosures and adjustments can be handled similarly. Most GPS survey nets (static or kinematic) end up with one or more interconnecting loops that are either internal from a single fixed point or external through two or more fixed network points. Loops should be closed off at the spacing indicated in Table 8-1. Loop closures should meet the criteria specified in Table 8-1, based on the total loop length. See also Chapter 10 for additional GPS loop closure checks.

(1) GPS control surveys may be conducted by forming loops between two or more existing points, with adequate cross-connections where feasible. Such alignment procedures are usually most practical on civil works navigation projects which typically require control to be established along a linear path, e.g., river or canal embankments, levees, beach renourishment projects, and jetties.

(2) Loops should be formed every 10 to 20 baselines, preferably closing on existing control.

(3) Connections to existing control should be made as opportunities exist and/or as often as practical.

(4) When establishing control over relatively large military installations, civil recreation projects, flood control projects, and the like, a series of redundant baselines forming interconnecting loops is usually recommended. When densifying Second- and Third-Order control for site plan design and construction, extensive cross-connecting loop and network configurations recommended by the FGCS for geodetic surveying are not necessary.

(5) On all projects, maximum use of combined static and kinematic GPS observations should be considered, both of which may be configured to form pseudo-traverse loops for subsequent field data validation and final adjustment.

8-4. GPS Network Design and Layout

A wide variety of survey configuration methods may be used to densify project control using GPS survey techniques. Unlike conventional triangulation, trilateration, and EDM traverse surveying, the shape, or geometry, of the GPS network design is not as significant. The following guidelines for planning and designing proposed GPS surveys are intended to support lower order (Second-Order, Class I, or 1:50,000 or less accuracy) control surveys applicable to USACE civil works and military construction activities. An exception to this would be GPS surveys supporting structural deformation monitoring projects where relative accuracies at the centimeter level or better are required over a small project area.

a. Newly established GPS control may or may not be incorporated into the NGRS, depending on the adequacy of the connection to the existing NGRS network, or whether it was tied only internally to existing project control.

b. Of paramount importance in developing a network design is to obtain the most economical coverage within the prescribed project accuracy requirements. The optimum network design, therefore, provides a minimum amount of baseline/loop redundancy without an unnecessary amount of "over-observation." Obtaining this optimum design (cost versus accuracy) is difficult and constantly changing due to evolving GPS technology and satellite coverage.

c. GPS survey layout schemes. The planning of a GPS survey scheme is similar to that for conventional triangulation or traversing. The type of survey design adopted is dependent on the GPS technique employed and the requirements of the user.

(1) GPS networking. A GPS network is proposed when established survey control is to be used in precise network densification (1:50,000-1:100,000). For lower order work (i.e., less than 1:50,000), elaborate network schemes are unnecessary and less work-intensive GPS

survey extension methods may be used. When the networking method is selected, the surveyor should devise a survey network that is geometrically sound. Triangles that are weak geometrically should be avoided. The networking method is practical only with static, pseudo-kinematic, and kinematic survey techniques. Figure 8-6 shows an example of a step-by-step method to build a GPS survey network.

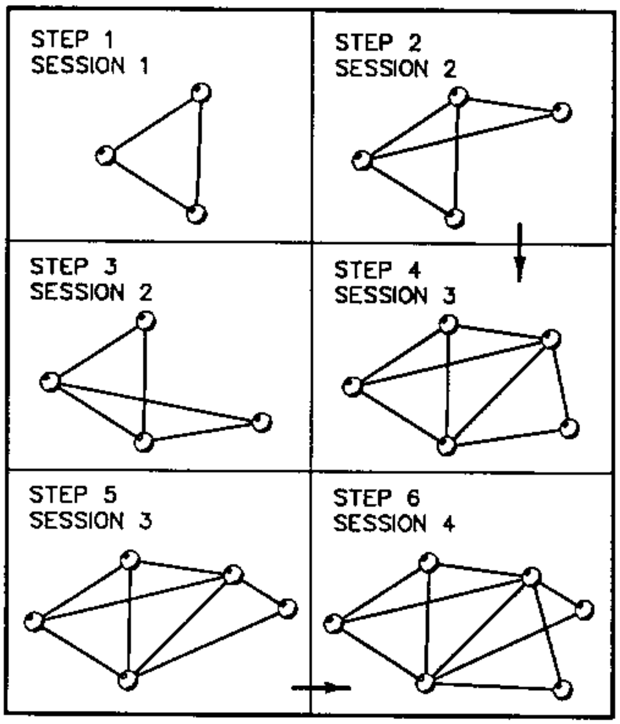


Figure 8-6. GPS network design

(2) GPS traversing. Traversing is the method of choice when the user has only two or three receivers and required accuracies are 1:5,000-1:50,000. Traversing with GPS is done similar to conventional methods. Open-end traverses are not recommended when 1:5,000 accuracies or greater are required. Since GPS does not provide sufficient point positioning accuracies, the surveyor must have a minimum of one fixed (or known) control point, although three are preferred. A fixed control point is a station with known latitude-longitude-height or easting-northing-height. This point may or may not be part of the NGRS. If only one control point is used and the station does not have a known height, the user will be unable to position the unknown stations. When performing a loop traverse, the surveyor should observe a check angle or check azimuth using conventional survey techniques to determine if the known station has been disturbed. If azimuth targets are not visible, and a check angle cannot be observed, a closed traverse involving one or more control points is recommended. Again, a check angle or check azimuth should be observed from the starting control station. If a check angle is not performed, the survey can still be completed. However, if the survey does not meet specified closure requirements, the surveyor will be unable to assess what control point may be in error. If a check angle or check azimuth cannot be observed, a third control point should be tied into the traverse (Figure 8-7). This will aid in determining the cause of misclosure.

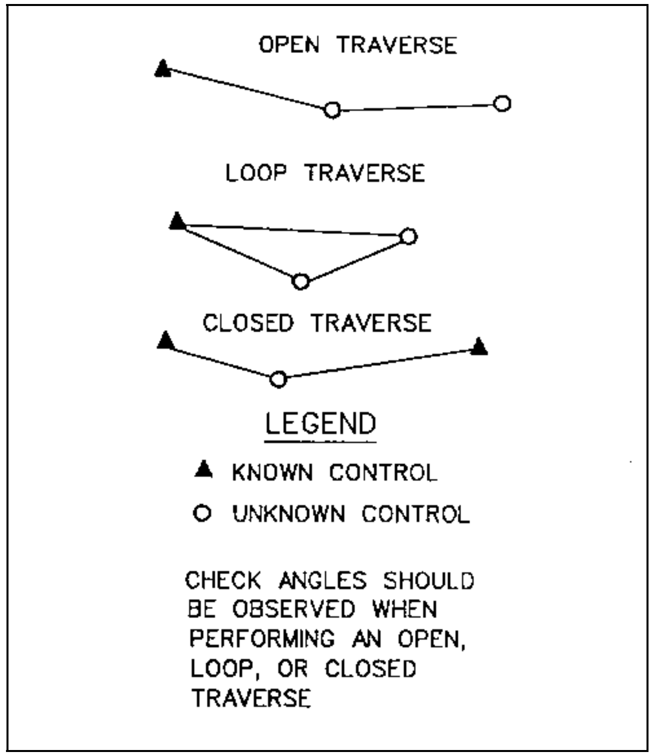


Figure 8-7. GPS traversing schemes

(3) GPS spur shots. Spurs are an acceptable method when the user has only two receivers or only a few control points are to be established. Spur lines should be observed twice during two independent observing sessions. Once the first session is completed, the receivers at each station should be turned off and the tripod elevations changed. This procedure is similar to performing a forward and backward level line. It is important that the tripods be moved in elevation and replumbed over the control station between sessions. If this step is not implemented, the two baselines cannot be considered independent. Figure 8-8 shows an example of a spur line. Spurs are most applicable to static survey and relative positioning (code phase) techniques.

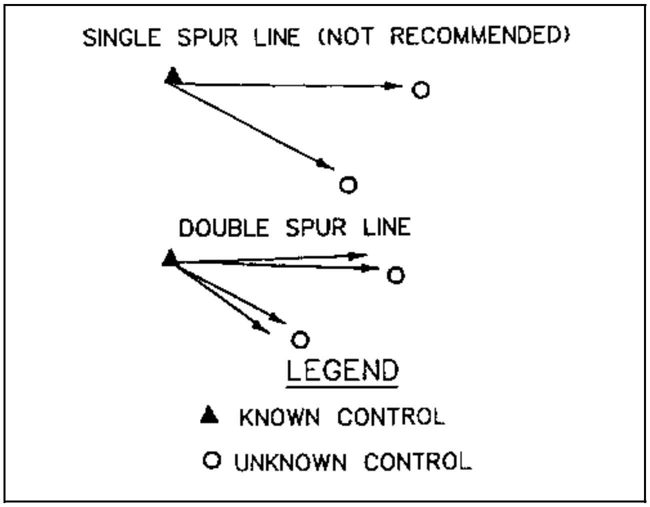


Figure 8-8. GPS spur line

8-5. GPS Techniques Needed for Survey

After a GPS network has been designed and laid out, a GPS survey method or technique needs to be considered. The concepts for each method were discussed in Chapter 6 and the procedures are discussed in Chapter 9. The most efficient method should be chosen in order to minimize time and cost while meeting the accuracy requirements of a given survey project. Once a technique is chosen, the following can be set up: equipment requirements, observation schedules, and sessions designations and planning functions.

a. General equipment requirements. The type of GPS instrumentation used on a project depends on the accuracy requirements of the project, GPS survey technique, project size, and economics. Most USACE projects can be completed using a single-frequency receiver. Dual-frequency receivers are recommended as baseline lengths approach or exceed 50 km. This length may also vary depending on the amount of solar activity during the observation period. Using a dual-frequency receiver permits the user to solve for possible ionospheric and tropospheric delays which can occur as the signal travels from the satellite to the receiver antenna.

(1) Number of GPS receivers. The minimum number of receivers required to perform a differential GPS survey is two. The actual number used on a project will depend on the project size and number of available instruments/ operators. Using more than two receivers will often increase productivity and allow for more efficient field observations. For some kinematic applications, two reference (set at known points) receivers and at least one rover are recommended.

(2) Personnel. Personnel requirements are also project dependent. Most GPS equipment is compact and light weight and only requires one person per station setup. However, some cases where a station is not easily accessible or requires additional power for a data link, two individuals may be required.

(3) Transportation. One vehicle is normally required for each GPS receiver used on a project. This vehicle should be equipped to handle the physical conditions that may be encountered while performing the field observations. In most cases, a two-wheel-drive vehicle should be adequate for performing all field observations. If adverse site conditions exist, a four-wheel-drive vehicle may be required. Adequate and reliable transportation is important when the observation schedule requires moving from one station to another between observation sessions.

(4) Auxiliary equipment. Adequate power should be available for all equipment (receivers, computers, lights, etc.) that will be used during the observations. Computers (386-based recommended), software, and data storage devices (floppy disks and/or cassette tapes) should be available for onsite field data reduction use. Other equipment required for conduct of a GPS survey should include tripods, tribrachs, measuring tapes, flagging, flashlights, tools, equipment cables, compass, and inclinometer. If real-time positioning is required, then a data link is also needed.

b. Observation schedules. Planning a GPS survey requires that the surveyor determine when satellites will be visible for the given survey area; therefore, the first step in determining observation schedules is to plot a satellite visibility plot for the project area. Even when the GPS becomes fully operational, full 24-hr coverage of at least four satellites may not be available in all areas.

(1) Most GPS manufacturers have software packages which at least predict satellite rise and set times. An excellent satellite plot will have the following essential information: satellite azimuths, elevations, set and rise times, and satellite PDOPs for the desired survey area. Satellite ephemeris data are generally required as input for the prediction software.

(2) To obtain broadcast ephemeris information, a GPS receiver collects data during a satellite window. The receiver antenna does not have to be located over a

known point when collecting a broadcast ephemeris. The data are then downloaded to a personal computer where they are used as input into the software prediction program. Besides ephemeris data for the software, the user is generally required to enter approximate latitude and longitude (usually scaled from a topographic map) and time offset from UTC for the survey area.

(3) From the satellite plot, the user can determine the best time to perform a successful GPS survey by taking advantage of the best combination of satellite azimuths, elevations, and PDOPs as determined by the satellite visibility plot for the desired survey area (for further information on favorable PDOP values, refer to Chapter 5). The number of sessions and/or stations per day depends on satellite visibility, travel times between stations, and the final accuracy of the survey. Often, a receiver is required to occupy a station for more than one session per day.

(4) A satellite polar plot (Figure 8-9), a satellite azimuth and elevation table (Figure 8-10), and a PDOP versus time plot (Figure 8-11) may be run prior to site reconnaissance. The output files created by the satellite prediction software are used in determining if a site is suitable for GPS surveying.

(5) Determination of session times is based mainly on the satellite visibility plan with the following factors taken into consideration: time required to permit safe travel between survey sites; time to set up and take down the equipment before and after the survey; time of survey; and possible time loss due to unforeseeable problems or complications. Station occupation during each session should be designed to minimize travel time in order to maximize the overall efficiency of the survey.

c. Session designations and planning functions. A survey session in GPS terminology refers to a single period of observation. Sessions and station designations are usually denoted by alphanumeric characters (0, 1, 2, A, B, C, etc.), determined prior to survey commencement.

(1) When only eight numeric characters are permitted for station/session designations, the following convention may be followed:

<u>12345678</u>

where

1 = type of monument with the following convention being recommended:

1 = known horizontal control monument
2 = known benchmark
3 = known 3D monument
4 = new horizontal control monument
5 = new benchmark
6 = new 3D monument
7 = unplanned occupation
8 = temporary 2D point
9 = temporary 3D point

2, 3, 4 = actual station number given to each station

5, 6, 7 = Julian day of year

8 = session number

(a) Example: Station Identifier: 40011821
Position: 12345678

(b) The numeral 4 in the number 1 position indicates the monument being established is a new monument where only horizontal position is being established.

(c) The 001 in the number 2, 3, and 4 position is the station number that has been given to the monument for this project.

(d) The 182 in the number 5, 6, and 7 position is the Julian day of the year. This is the same day as 1 July.

(e) The numeral 1 in the number 8 position identifies the session number during which observations are being made. If the receiver performed observations during the second session on the same day on the same monument, the session number should be changed to 2 for the period of the second session (then the total station identifier would be 40011822).

(2) When alpha characters are permitted for station/session designation, then a more meaningful designation can be assigned to the designation. The date of each survey session should be recorded during the survey as calendar dates and Julian days and used in the station/session designation. Some GPS software programs will require Julian dates for correct software operation. In addition to determination of station/session designations before the survey begins, the user (usually the crew chief) must:

(a) Determine the occupant of each station.

(b) Determine satellite visibility for each station.

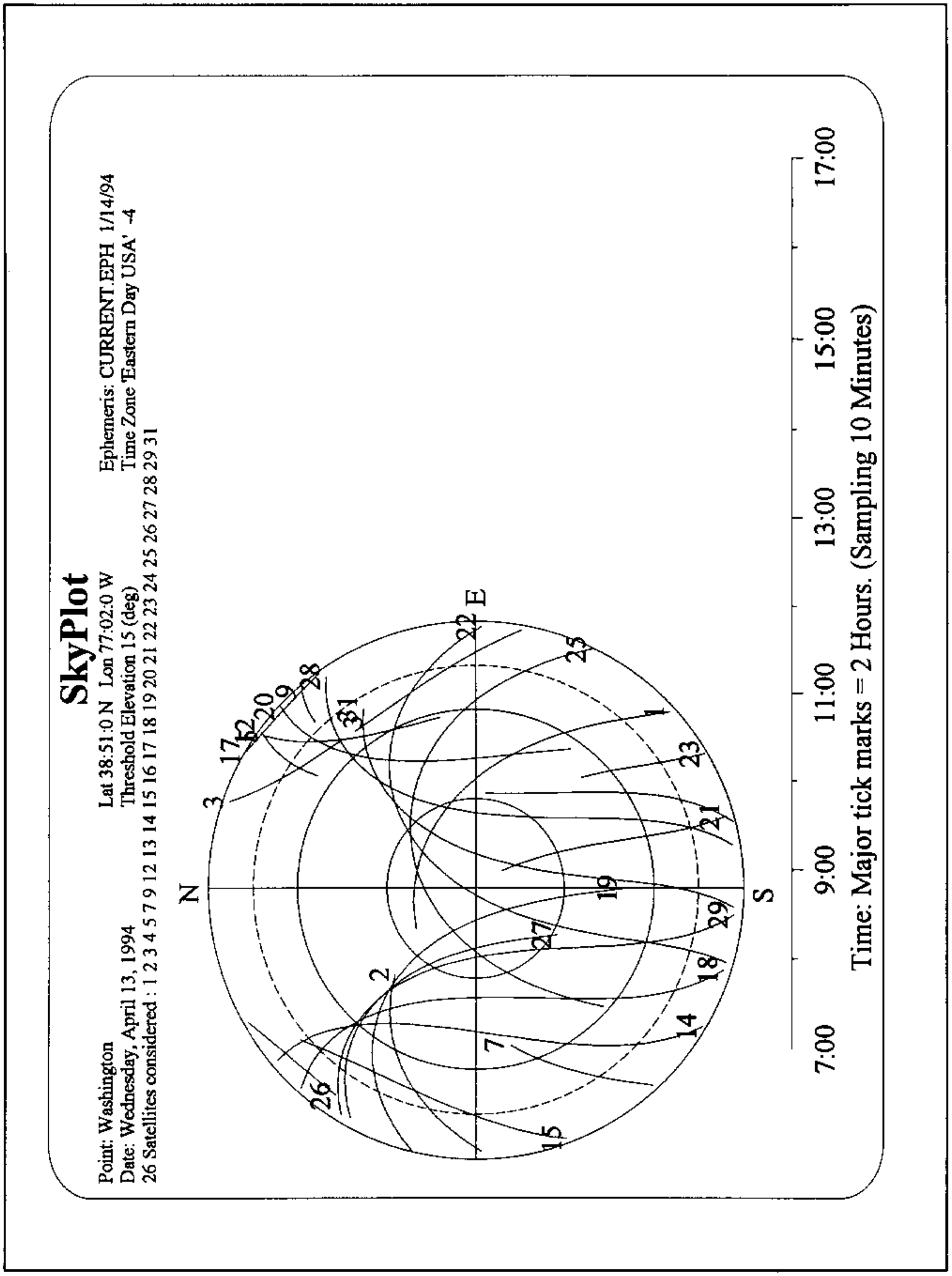


Figure 8-9. Satellite polar plot

SV Constellations

Point: Washington | Lat 38:51:0 N Lon 77:02:0 W | Ephemeris: CURRENT.EPH 1/14/94
Date: Wednesday, April 13, 1994 | Threshold Elevation 15 (deg) | Time Zone 'Eastern Day USA' -4
26 Satellites considered : 1 2 3 4 5 7 9 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 31
Sampling Rate: 10 Minutes

Constellation	T Rise	T Set	dT	PDOP Rise	PDOP Set
4 5 13 16 20 24 26	0:00	0:10	0:10	2.5	2.5
4 13 16 20 24 26	0:10	0:20	0:10	2.5	2.5
3 4 13 16 20 24 26	0:20	0:30	0:10	1.8	1.8
3 4 16 20 24 26	0:30	0:40	0:10	1.9	1.9
3 16 17 24 26	0:40	1:40	1:00	2.9	3.2
3 16 17 23 24 26	1:40	2:00	0:20	2.5	2.5
3 16 17 23 26	2:00	2:40	0:40	3.6	4.4
3 9 16 17 23 26	2:40	3:40	1:00	2.7	3.2
3 9 12 16 17 21 23 26	3:40	3:50	0:10	1.8	1.8
3 9 12 17 21 23 26	3:50	4:10	0:20	2.1	2.2
3 9 12 17 21 23 26 28	4:10	4:20	0:10	2.0	2.0
1 3 9 12 17 21 23 26 28	4:20	4:30	0:10	1.9	1.9
1 3 9 12 17 21 23 26	4:30	4:40	0:10	2.0	2.0
1 9 12 17 21 23 26	4:40	5:00	0:20	2.2	2.2
1 9 12 17 21 23	5:00	5:40	0:40	5.3	4.7
1 5 9 12 17 21 23	5:40	6:00	0:20	3.3	3.2
1 5 9 12 21 23	6:00	6:10	0:10	3.3	3.3
1 5 9 12 20 21 23	6:10	6:20	0:10	2.9	2.9
1 5 9 12 20 21 23 25	6:20	7:00	0:40	2.1	2.1
1 5 12 20 21 23 25	7:00	7:20	0:20	2.4	2.4
1 5 12 15 20 21 23 25	7:20	7:30	0:10	2.0	2.0
1 5 15 20 21 23 25	7:30	8:00	0:30	2.1	1.9
1 5 15 20 21 25	8:00	8:40	0:40	2.8	2.1
1 14 15 20 21 25	8:40	9:00	0:20	2.3	2.3
1 14 20 21 25	9:00	9:10	0:10	2.5	2.5
1 14 20 21 22 25	9:10	9:20	0:10	2.4	2.4
1 14 20 22 25	9:20	10:00	0:40	2.7	2.8
1 14 20 22 25 29	10:00	10:10	0:10	2.3	2.3
1 14 22 25 29	10:10	10:50	0:40	2.8	2.6
3 14 22 25 29	10:50	11:10	0:20	3.1	3.2
3 14 22 25 28 29	11:10	11:20	0:10	2.5	2.5
3 14 18 22 25 28 29	11:20	12:00	0:40	1.9	2.1
3 14 18 22 25 28 29 31	12:00	12:20	0:20	1.9	1.8
3 18 22 25 28 29 31	12:20	12:40	0:20	2.2	2.2
3 18 19 22 28 29 31	12:40	12:50	0:10	2.0	2.0
18 19 22 28 29 31	12:50	13:50	1:00	3.0	4.3
18 19 22 27 28 29 31	13:50	14:50	1:00	2.8	2.2
18 19 27 28 31	14:50	15:00	0:10	3.1	3.1
15 18 19 27 28 31	15:00	15:20	0:20	2.8	2.7
2 15 18 19 27 28 31	15:20	15:40	0:20	1.9	1.8
2 15 19 27 28 31	15:40	15:50	0:10	2.1	2.1
2 15 19 27 31	15:50	16:00	0:10	2.9	2.9
2 7 15 19 27 31	16:00	17:20	1:20	2.4	2.7
2 7 15 19 27	17:20	17:50	0:30	6.8	6.8
2 7 14 15 19 27	17:50	18:00	0:10	5.5	5.5
2 7 13 14 15 27	18:00	18:20	0:20	2.9	2.8
2 4 7 13 14 15 27	18:20	18:40	0:20	2.6	2.4
2 4 7 13 14 15	18:40	18:50	0:10	2.4	2.4
2 4 7 9 13 14 15	18:50	19:00	0:10	2.0	2.0
2 4 7 9 12 13 14 15	19:00	19:20	0:20	2.1	2.3
2 4 7 9 12 13 14	19:20	19:30	0:10	2.8	2.8
2 4 7 9 12 13 14 24	19:30	20:20	0:50	2.2	2.2
2 4 5 7 9 12 13 14 24	20:20	20:50	0:30	1.9	1.7
2 4 5 7 12 13 24	20:50	21:00	0:10	2.5	2.5
4 5 7 12 13 24	21:00	21:30	0:30	3.4	3.7
4 5 7 12 13 18 24	21:30	21:40	0:10	2.9	2.9
4 5 7 12 13 16 18 24	21:40	21:50	0:10	2.7	2.7
4 5 7 12 13 16 18 20 24	21:50	22:00	0:10	1.7	1.7
4 5 7 13 16 18 20 24	22:00	22:30	0:30	1.9	2.0
4 5 13 16 18 20 24	22:30	23:20	0:50	2.4	2.6
4 5 13 16 20 24	23:20	23:50	0:30	3.0	2.7
4 5 13 16 20 24 26	23:50	24:00	0:10	2.5	2.5

Figure 8-10. Satellite azimuth and elevation table

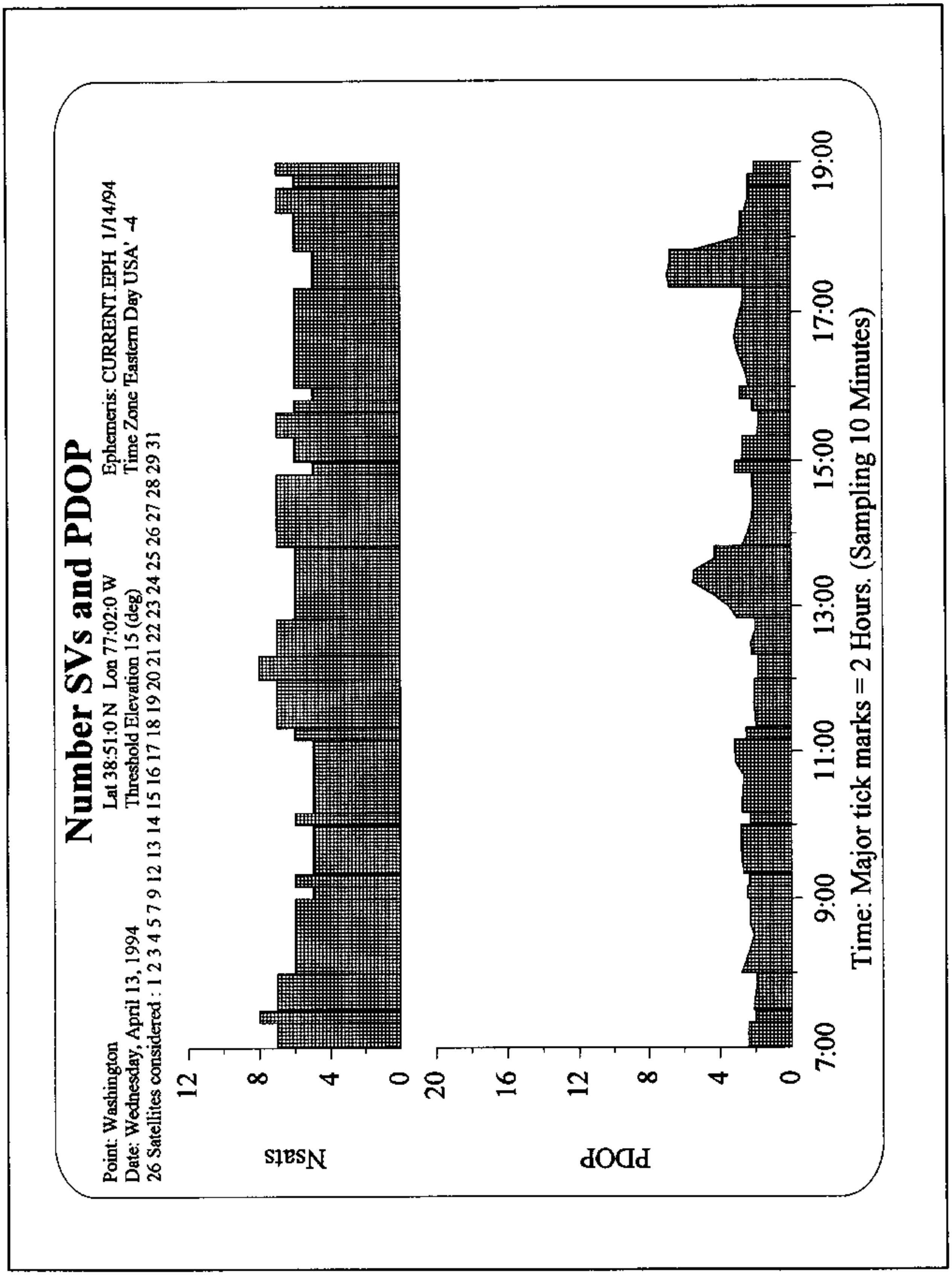


Figure 8-11. PDOP versus time plot

(c) Require site reconnaissance data for stations to be occupied. Remember the same person who performed the initial site reconnaissance may not be the individual performing the survey; therefore, prior determined site reconnaissance data may require clarification before survey commencement.

(d) Develop a project sketch.

(e) Issue explicit instructions on when each session is to begin and end.

(f) Require a station data logging sheet completed for each station. Figures 8-12 and 8-13 are examples of various station logs used in USACE, along with blank forms which may be used as worksheets. Standard bound field survey books may be used in lieu of separate log/work sheets.

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

PROJECT NAME: COYOTE DAM — LOCALITY: UKIAH, CA
OBSERVER: LARRY LAMB — AGENCY/FIRM: COE, SACRAMENTO DIST.
RECEIVER: TRIMBLE 4000 SL — S/N: 2820A00223
ANTENNA: TRIMBLE MICRO SL — S/N: 2816A00224
DATA RECORDING UNIT: RECEIVER — S/N: 2820A00223
TRIBRACH: WILD GDF 22 — S/N: N/A — LAST CALIBRATED: 4/24/89

	SESSION 1	SESSION 2	SESSION 3
STATION NAME	PIER 2	PIER 2	PIER 2
STATION NUMBER	2002	2002	2002
DAY OF YEAR	115	115	115
DATE MM DD YY	04/25/89	04/25/89	04/25/89
UTC TIME OF OBSERVATION	START 04:56 STOP 05:55	START 06:10 STOP 07:38	START 07:55 STOP 09:20

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	0.120 0.120 0.119 4 13/16 IN = 0.121 M MN = 0.120 M	0.116 0.116 0.116 4 9/16 IN = 0.116 M MN = 0.116 M	0.123 0.124 0.124 4 14/16 IN = 0.124 M MN = 0.1238 M
SLOPE @ END	4 13/16 4 13/16 4 13/16 0.120 M = 4 13/16 IN MN = 0.120 M	4 9/16 4 9/16 4 9/16 0.116 M = 4 9/16 IN MN = 0.116 M	4 13/16 4 14/16 4 14/16 0.123 M = 4 13/16 IN MN = 0.1230 M
MN ADJ TO VERT	0.120 M	0.116 M	0.1234 M

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT	39-12-30	39-12-22.64	39-12-30	39-12-22.48	39-12-30	39-12-22.81
LONG	123-10-30	123-10-33.42	123-10-30	123-10-33.20	123-10-30	123-10-33.62
HT	244.0	210.6	244.0	199.8	244.0	222.8
PDOP	3.6		4.8		4.0	
SVS TO TRACK	02, 03, 06, 09, 11, 12, 13, 14		02, 03, 06, 09, 11, 12, 13, 14		03, 06, 09, 11, 12, 13, 14, 16	

LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START	21:55	21:56	23:38	23:10	01:20	00:55
STOP	22:55	22:55	00:38	00:38	02:20	02:20

PAGE 1

Figure 8-12. Sample GPS data logging sheet (Continued)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

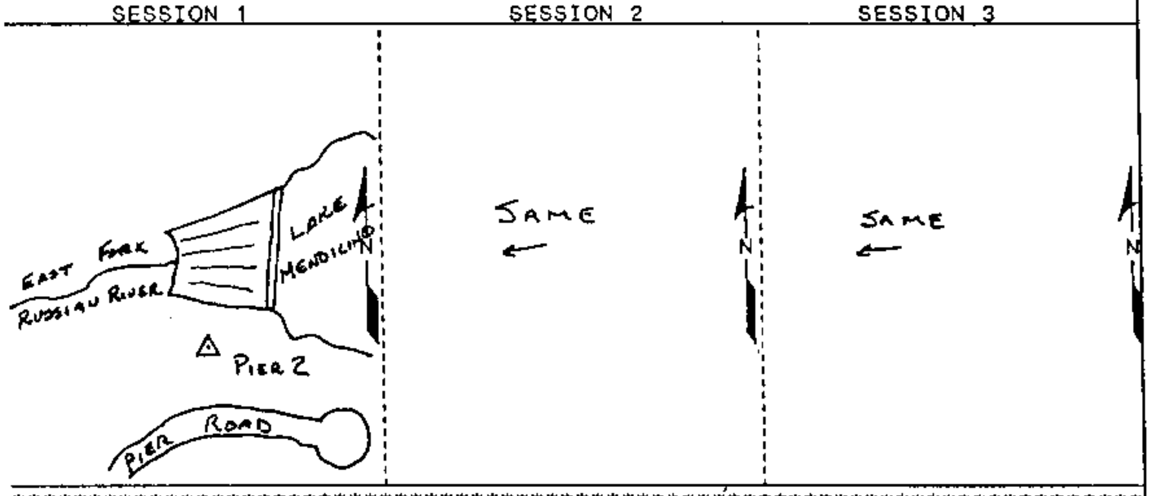
****

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	100 ft	100 ft	35 ft
POWER SUPPLY	12v DC	12v DC	12v DC
WEATHER CONDITIONS	CLEAR, COOL 45°	CLEAR, COOL 40°	CLEAR, BREEZY 40°
MONUMENT TYPE	'C' (SET IN PIER)	← SAME	SAME
EXACT STAMPING	PIER 2 1953	← "	"
AGENCY CAST IN DISK	COE	← "	"

****

SKETCH OF SITE

SESSION 1 SESSION 2 SESSION 3



****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

THE ANTENNA WAS MOUNTED DIRECTLY OVER PIER 2 WITH NO TRIPOD USED.

ANTENNA HEIGHT WAS MEASURED VERTICALLY FROM GROUND PLANE TO BRASS DISK.

****

PAGE 2

Figure 8-12. (Concluded)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

PROJECT NAME ____________ LOCALITY ____________
OBSERVER ____________ AGENCY/FIRM ____________
RECEIVER ____________ S/N ____________
ANTENNA ____________ S/N ____________
DATA RECORDING UNIT ____________ S/N ____________
TRIBRACH ____________ S/N ____________ LAST CALIBRATED: ____________

	SESSION 1		SESSION 2		SESSION 3	
STATION NAME						
STATION NUMBER						
DAY OF YEAR						
DATE MM DD YY						
UTC TIME OF OBSERVATION	START	STOP	START	STOP	START	STOP

ANTENNA HEIGHT MEASUREMENTS

	SESSION 1	SESSION 2	SESSION 3
SLOPE @ BEGINNING	___ ___ ___ ___ IN =___ M MN = ______ M	___ ___ ___ ___ IN =___ M MN = ______ M	___ ___ ___ ___ IN =___ M MN = ______ M
SLOPE @ END	___ ___ ___ ___ M =___ IN MN = ______ M	___ ___ ___ ___ M =___ IN MN = ______ M	___ ___ ___ ___ M =___ IN MN = ______ M
MN ADJ TO VERT	______ M	______ M	______ M

	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION	PROGRAMMED REFPOS	FIELD POSITION
LAT						
LONG						
HT						
PDOP						
SVS TO TRACK						
LOCAL TIME:	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL	SCHEDULED	ACTUAL
START						
STOP						

PAGE 1

Figure 8-13. Worksheet 8-3, GPS data logging sheet (Continued)

U.S. ARMY CORPS OF ENGINEERS
GPS DATA LOGGING SHEET

****

	SESSION 1	SESSION 2	SESSION 3
ANT CABLE LENGTH	________	________	________
POWER SUPPLY	________	________	________
WEATHER CONDITIONS	________	________	________
MONUMENT TYPE	________	________	________
EXACT STAMPING	________	________	________
AGENCY CAST IN DISK	________	________	________

****

SKETCH OF SITE

SESSION 1	SESSION 2	SESSION 3
N	N	N

****

Describe any abnormalities and/or problems encountered during the survey, include session number, time of occurance and duration.

****

PAGE 2

Figure 8-13. (Concluded)